Mid-Frequency Propagation Modeling Using the Waveguide Invariant

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LONG-TERM GOALS

Random variability in shallow water will induce variability in a propagating acoustic field. The long-term goal of this research is to quantify how random variability in the ocean environment translates into random variability in the acoustic field and the associated signal processing algorithms in the mid-frequency (1-10 kHz) band. In the present funding cycle, the emphasis is on the waveguide invariant.

OBJECTIVES

Constructive and destruction interference is an inevitable consequence of multipath acoustic propagation in shallow water. If the ocean environment is sufficiently benign, the so-called waveguide invariant describes the resulting interference pattern. The waveguide invariant has traditionally been regarded as a low-frequency phenomenon. The objectives of the present work are twofold: first, to extend the waveguide invariant concept so it may be incorporated into mid-frequency signal processing algorithms, and second to quantify the limitations on these algorithms imposed by shallow-water internal waves.

APPROACH

The approach is a mixture of data analysis, theoretical development, and numerical modeling. Dr. Dajun Tang of the University of Washington Applied Physics Laboratory (APL-UW) is a key individual in acquiring suitable acoustical and environmental data sets that can be used in the analysis. Dr. Lisa Zurk of Portland State University is a key individual in developing the signal processing algorithms.

WORK COMPLETED

Under current support, the PI served as co-chair and co-organizer of the *2nd International Workshop on Acoustic Interference Phenomena and Signal Processing*. The first such workshop was held in San Francisco in 2001 under support from ONR. That workshop brought together American and Russian investigators interested how the complexities of multipath propagation in the ocean could be exploited in practical signal processing algorithms. The 2013 workshop was held in Moscow and concerned advances in the field made over the last decade. Consistent with the growing international interest in

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the topic, the second workshop also included investigators from China. Support for the workshop was obtained from ONR-Global as well as the Russian Science Foundation, the Russian Acoustical Society, and the Acoustical Society of America (ASA).

At present, the PI is working as editor of the conference proceedings. The proceedings will be published by the ASA as a Special Issue of the *Proceedings of Meetings on Acoustics* (POMA). Papers in POMA are reviewed, recognized by *Web of Science* and other Internet search engines, and freely available online through the ASA. The proceedings will make accessible the results of international research not normally available in the English language literature.

At a technical level, PI's work concentrated on verifying experimentally previous theoretical work and documenting the results. Under support from ONR during the previous funding cycle, a method called striation-based beamforming was developed. It was shown theoretically how striation-based beamforming permits one to estimate both the source-to-receiver range and the waveguide invariant; it had previously been thought that only the ratio between the two quantities was accessible [Rouseff and Zurk, 2011; Zurk and Rouseff, 2012]. Data collected during the 2011 Gulf Experiment (GulfEx11) were used in these initial tests. Both the source-to-receiver range and the numerical value of the waveguide invariant were estimated every 0.5 Hz over a 200 bandwidth centered at 3.5 kHz. The software developed in these initial tests should be sufficiently general as to be applied to other data sets, specifically those collected during the 2013 Transmission-Reverberation Experiment (TREx13). Mid-frequency TREx13 data were collected on a horizontal array at ranges from tens of meters to several kilometers and are ideal for testing different concepts related to the waveguide invariant.

RESULTS

The new capability to determine both the numerical value of the waveguide invariant and the source-receiver range was demonstrated successfully using experimental data. The 3.5 kHz GulfEx11 data collected at range 97 m showed the waveguide invariant $\beta = 0.95$, close to the canonical shallow-water value, $\beta = 1.0$. Applying striation-based beamforming to a normal-mode simulation of the GulfEx11 scenario yielded $\beta = 1.02 \pm 0.06$ and range $r = 101.9 \pm 2.4$ m. Applying striation-based beamforming to the actual GulfEx11 data gave $\beta = 0.98 \pm 0.12$ and $r = 97.5 \pm 10.3$ m. A caveat is that the acoustic data were matched filtered before applying the striation-based beamformer, a step that requires prior information about the transmitted waveform. Future work will try to eliminate the need to match filter the signal.

IMPACT/APPLICATIONS

The waveguide invariant is currently applied in practical sonar signal processing algorithms. Extending its usages to the mid-frequency regime is desirable.

RELATED PROJECTS

This project uses acoustical and environmental data collected in ONR-supported experiments like GulfEx and TREx. Collaboration with investigators from APL-UW in using these data sets will continue. Collaboration with investigators from Portland State University supported by the ONR Underwater Signal Processing will also continue.

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PUBLICATIONS

D. Rouseff, L. M. Zurk, and D. Tang, "Demonstration of striation-based beamforming in a shallow water waveguide," Proceedings of *2nd International Workshop on Acoustic Interference Phenomena and Signal Processing*, Moscow, Russia, June 17-21, 2013 [in press, refereed].

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HONORS/AWARDS/PRIZES

Excellent Reviewer Award, *IEEE Journal of Oceanic Engineering.*